NASA TECHNICAL TRANSLATION NASA TT F-14505

POSSIBILITY OF USING AN ATMOSPHERE BASED ON CO2 IN A POWER PLANT

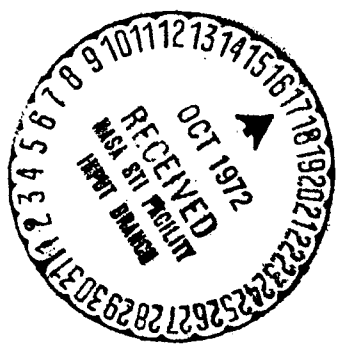
U. Ghezzi and L. De Luca

(NASA-TT-F-14505) POSSIBILITY OF USING AN ATMOSPHERE BASED ON CO2 IN A POWER PLANT U. Ghezzi, et al (Agnew Tech-Tran, Woodland Hills, Calif.) Jun. 1972 17 p CSCL 10A

N72-32074

Unclas
G3/03 43705

Translation of "Sulla possibilità di utilizzo di un'atmosfera a base di CO2 in un impianto di potenza", in L'Evoluzione della propulsione spaziale negli anni '70 (Evolution of space propulsion in the '70s), International Technical and Scientific Conference on Space, 10th, Rome, Italy, March 9-11, 1970, Official Proceedings pp. 151, 153-164.



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 JUNE 1972

U. GHEZZI (*)

L. DE LUCA (**)

ON THE POSSIBILITY OF UTILIZING A CO_2 BASED ATMOSPHERE IN A POWERPLANT

(*) Professor in charge, "Istituto di Macchine" Politocnico Milan

(**) Researcher C. N. P. M. Politocnico Milan

Translated by: AGNEW TECH TRAN
5115 Serrania Avenue
Woodland Hills, Calif.
91364

I

1) INTRODUCTION

It has to be realized that with the need for having at one's disposal a power source for space uses, there are strong weight limitations connected with the difficulty of transporting a payload into space. It is therefore necessary that the power plant - besides offering guarantees of high reliability - have construction and operational characteristics which minimize the weight. It is clear that with the plant having to function in space, it will be necessary not only to transport the constituent machinery but also, at least in part, the fuel with the relative burning compound. In this case, the plant's weight is to be understood as the combined weight of the structural components and that of the reagents. The type - and thus the weight - of the structure and the quantity of the propellents to be transported depend both on the adopted layout of the plant and the operating conditions (for example the power to be delivered and the required working time).

At this point, the case is examined where the plant has to work on a given planet of a certain atmosphere and consideration is given to the possibility of using the constituent fluid of the atmosphere as working fluid. Then the case is considered where such a solution becomes convenient by saving on the total weight in respect to a plant completely independent from its surrounding environment.

2) STATEMENT OF THE PROBLEM

A gas turbine is assumed to be used as the power

plant. In principle, it is possible to work with an open cycle as well as with a closed cycle. In order to establish the concepts, the open cycle is considered here. Hydrogen is used as fuel and oxygen as the combustion compound.

As far as the external atmosphere is concerned, the following cases have been examined:

1) The working fluid is composed only of products from the combustion reaction between oxygen and hydrogen without using the external atmosphere.

2) The combustion takes place again between oxygen and hydrogen; the products of reaction are now also used for heating up the atmospheric fluid with the help of a heat exchanger.

3) The atmospheric fluid is involved directly in the combustion reaction between hydrogen and oxygen.

1) In the first case, the plant could be laid out as shown in Fig. 1. Should the hydrogen and oxygen in the beginning be in a liquid state, the plant consists of two tanks under pressure, a possible preheater, a combustion chamber and a turbine.

The turbine entry temperature should be the same in all three cases examined, and considering the purpose and the nature of the plant is in fact $Ta=1500^{o}K$.

It is now necessary to examine the hydrogen-oxygen combustion reaction in order to determine the conditions which produce the required turbine entry temperature and relative reaction heat. From this latter parameter, as-

suming the overall output value of the plant is known, one can determine the power delivered. The confrontation between the various projected solutions will be made by considering the total weight of the plant necessary to produce a single power value.

In Fig. 2, the development of the adiabatic combustion temperature of the hydrogen-oxygen mixture is shown as a function of mixture relationship $\alpha = NO/NH$ where NO is the number of oxygen gram atoms and NH is the number of hydrogen gram atoms. The calculations are made by determining the conditions of thermodynamic balance; numerically, with the help of an electronic computer the system is to be solved which consists of the mass conservation and enthalpy equations as well as of the experimental relations defining the conditions of chemical balance. For our calculations, the UNIVAC 1108 computer donated to the Milan Polytechnical Computation Center has been used. The pressure in the combustion chamber was set equal to 10 atmospheres.

From the graph in Fig. 2, one can see that the relation of the mixture to be used within the limits of approximate calculations is $\alpha = 5.25$.

Table 1 states the molar composition of the combustion products corresponding to the stated operating condition of the burning compound. The reaction heat Q_1 related to the weight of the reacting mixture used in the case examined is $Q_1 = 340$ Kcal/kg. If we indicate the total plant output with the symbol η_1, we find that the power to weight

ratio of the mixture is:

$$Lu_1 = \eta_1 Q_1$$

In order to obtain from the plant a certain power N for a certain operating time T, the weight P of the required hydrogen-oxygen mixture is:

$$P_1 = \frac{N.\ T}{Lu} = \frac{N.\ T}{Q_1 \eta_1}$$

In Fig. 3 the lines stating the weight P are given in function of the operating time T and parametered in η_1. One could trace the lines assuming a single value for the power N and still assuming the above determined value for the unitary reaction heat Q_1.

2) The case is now examined where the atmospheric fluid is heated in a heat exchanger. If the pressure of the atmospheric fluid is lower than that at which combustion occurs, the plant is the type shown in Fig. 4. It is assumed that the atmospheric fluid is essentially composed of CO_2, since this gas seems to exist in abundance on several planets of the solar system (1). The unitary efficiency of the exchanger, which is assumed to be countercurrent, is then stated, and it is also assumed that the combustion products from the hydrogen-oxygen reaction and the heated fluid are sent to two different turbines.

Indicating by P_2 the weight of the hydrogen-oxygen mixture to be transported and by P at the weight of the atmospheric fluid to be utilized, the exchanger shows this type of thermic balance:

$$C_p P_2 (T_f - T_a) = C_{Pat} P_{at} (T_a - T_o)$$

where To is the atmospheric fluid temperature upon exit from the compressor and Ta the temperature upon exit from the exchanger, i. e. upon entry to the turbine.

Developing the preceding relations, one obtains:

$$P_{at} = \frac{C_p}{C_{pat}} \quad \frac{T_f - T_a}{T_a - T_o} \cdot P_2$$

Let us consider a mixture with a combustion temperature of Tl = 2100°K. By examining the numerical data, it can be seen that for this combustion temperature the corresponding mixture ratio is $\alpha = 3.2$ The specific heat ranges are calculated by taking into consideration both the different temperatures and the different combustion products. In this way it is possible to calculate the necessary range of CO_2 to get a turbine temperature of 1500°K.

With Q_2, the reaction heat corresponding to the combustion reaction under consideration is given by:

$$L_{u_2} = \eta_2 Q_2$$

with η_2 as the total plant output in the examined case. Therefore, it also allows that

$$P_2 = \frac{N T}{\eta_2 Q_2}$$

Showing with ΔP_2 the structural weight excess (taking into account the greater complexity of the examined plant as compared to the preceding one), if again we refer

to the unit of produced power, one comes to the conclusion that the weight of the propellents plus the plant's overweight is given by:

$$P_2 = \Delta P_2 + \frac{T}{\eta_2 \Omega_2}$$

In Fig. 5, the development of P_2 is shown as a function of operating time T, assuming ΔP_2 constant with η_2 varying.

3) The case is now examined where a hydrogen-oxygen-carbonic anhydride reaction is made simultaneously: a suitable plant layout would be the type shown in Fig. 6. The desired combustion temperature can be obtained by the following type of reaction:

$$2H_2 + O_2 + 0.2\ CO_2$$

as shown by the graph in Fig. 7. From the above stated results it is clear that a small quantity of carbonic anhydride is sufficient to drastically lower the combustion temperature of the mixture. It therefore immediately appears that the choice of the proposed kind of system is not necessarily very convenient, except in special working conditions.

Proceeding as in the previous case, we find that:

$$P_3 = \Delta P_3 + \frac{N\ T}{\eta_3\ \Omega_3}$$

3) COMPARISON BETWEEN THE EXAMINED CASES

A comparison is established between the examined cases

in order to define which would be the most convenient system in relation to working conditions and the required services. It is clear that the most convenient system will be the one which has the lowest weight per power delivered (with a unitary value for the power taken as an example).

Fig. 8 shows the development of the weight ranges during variations of operating time in relation to the first two proposed solutions, assuming a fixed value for ΔP. The gradient of line a is $1/\eta_1 Q_1$ while the gradient of line b is $1/\eta_2 Q_2$. It is clear that the first plant design would be more convenient than the second one, whatever the value of the operating time is in this case:

$$\frac{1}{\eta_2 Q_2} > \frac{1}{\eta_1 Q_1}$$

However, if the result were:

$$\frac{1}{\eta_2 Q_2} < \frac{1}{\eta_1 Q_1}$$

it would be possible to define a point of intersection between the two lines, corresponding to a operating time T^*: under these conditions for $T < T^*$, it would be appropriate to use the first plant, while for $T > T^*$, the second solution would be more advantageous. We must now see if the following case could be verified:

$$\eta_2 Q_2 > \eta_1 Q_1$$

$$\eta_2 > \eta_1 \frac{Q_1}{Q_2}$$

In general, given the greater complexity of the second

plant, one will have $\eta_2 < \eta_1$. Nevertheless, the high combustion temperatures of the second case result in Q_2 being much higher that Q_1 and with the existence range of Q_1 and Q_2 being much wider than η_1 and η_2, one can conclude that the above relation would in general be proved. For example, in the case of the above examined reactions, with Q_2 = 570 Kcal/kg, we find:

$$\frac{Q_1}{Q_2} = 0.615$$

Therefore, it is seen that the discriminating operating time would be inversely proportional to the difference of $\eta_2 Q_2 - \eta_1 Q_1$.

The discriminating operating time T is obtained through the reaction:

$$T^* = \frac{P_2}{\frac{1}{\eta_1 Q_1} - \frac{1}{\eta_2 Q_2}}$$

An analoguous comparison can be made between the first and the third case: again, there will be a discriminating time if $\eta_3 Q_3 > \eta_1 Q_1$.

In the case under examination it would be: Q_3 = 420 Kcal/kg.

Because Q_3 is of the same order of magnitude as Q_1, while naturally for the reasons already stated one has $\eta_3 < \eta_1$ it follows that the intersection between the two lines will show very high operating times. The adoption of a plant of

the third kind is therefore in general not suitable, at least in the case where the atmospheric fluid is CO_2.

In the examined case, the result would in fact be:

$$\frac{Q_1}{Q_3} = 0.83$$

With the total output value as established in the first case, the discriminating output in the third case is higher than the one in the second case.

Fig. 9 shows a block diagram for calculation of the burning temperature in the cases we have examined.

4) CONCLUSION

In the examined study we have tried to indicate a suitable method for analyzing possibility and in particular the suitability of using the possible atmosphere of a planet in a power production plant.

Numerical considerations in relation to stated characteristics of the examined plants have purposely been avoided, for their functioning methods are felt to be summed up in the total plant output.

Also, no special conjectures have been made as far as the numerical output value is concerned, for this depends strongly on the type of plant adopted, the particular atmospheric conditions and so on.

What is of interest here is to point out the conditions for existence of an output and a discriminating time and a suitable method for determining such conditions.

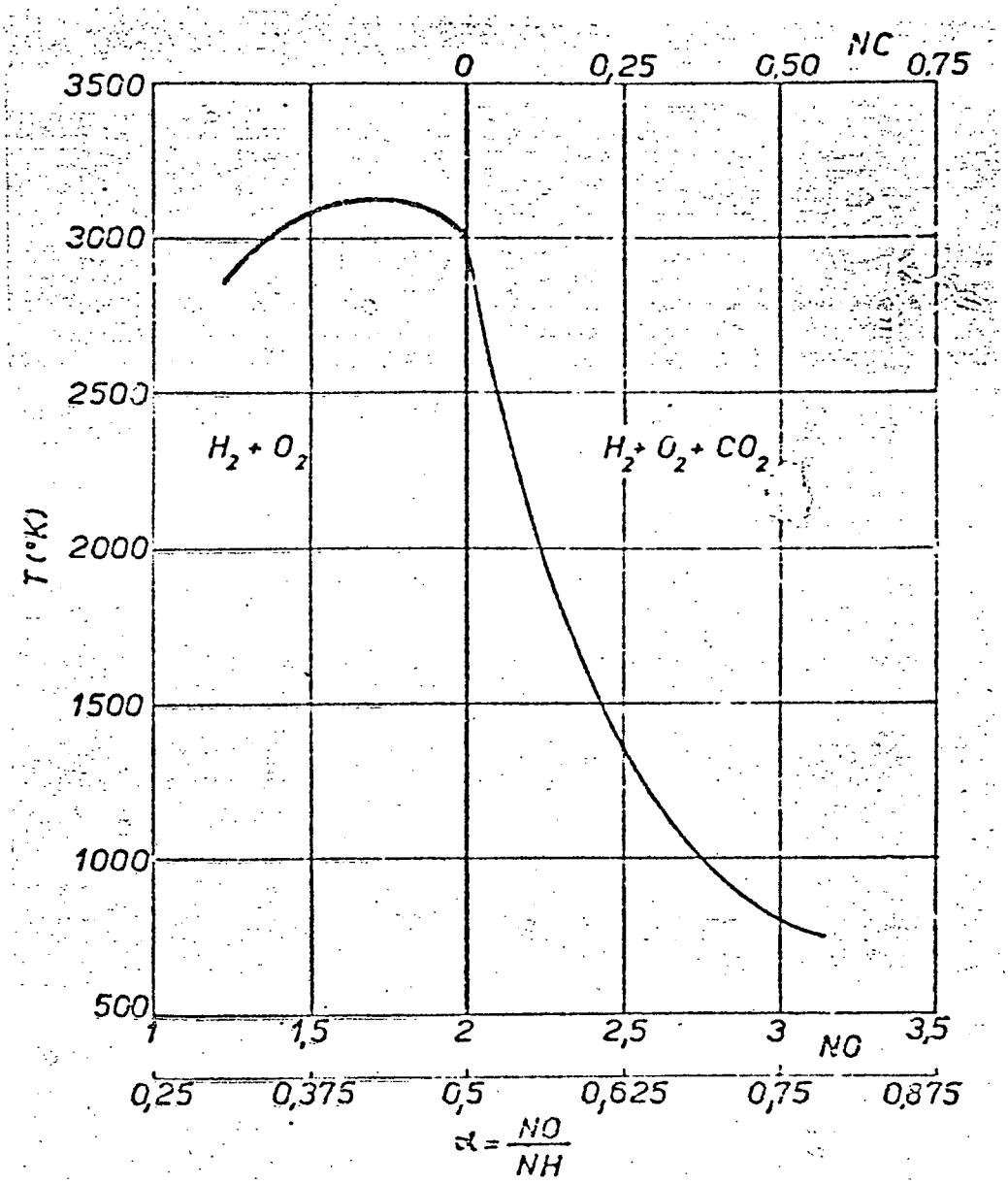


FIG. 7 - Andamento della temperatura di combustione delle miscele $H_2 + O_2$ e $H_2 + O_2 + CO_2$ (NH = 4) .

Fig. 7 - Development of the combustion temperature of the mixture $H_2 + O_2$ and $H_2 + O_2 + CO_2$ (NH = 4)

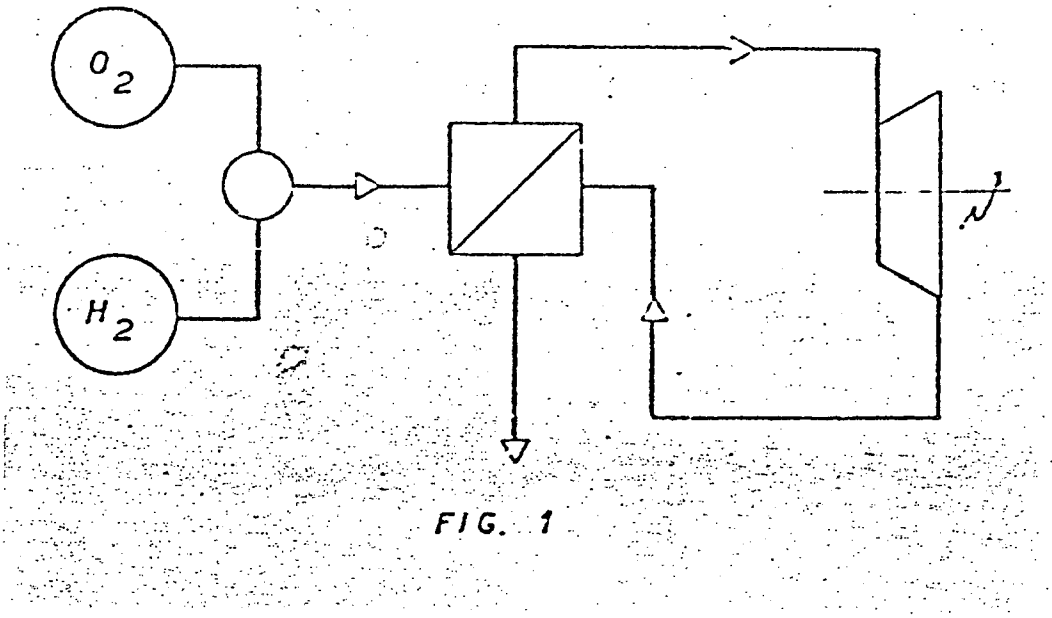
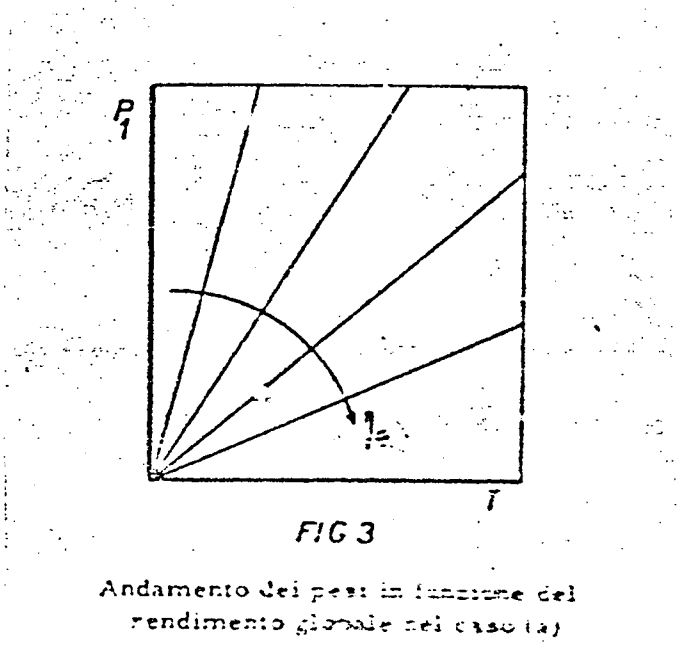


Fig. 1 - Plant layout for case (a).



Andamento dei pesi in funzione del rendimento globale nel caso (a)

Fig. 3 - Development of weights as a function of the total output in case (a).

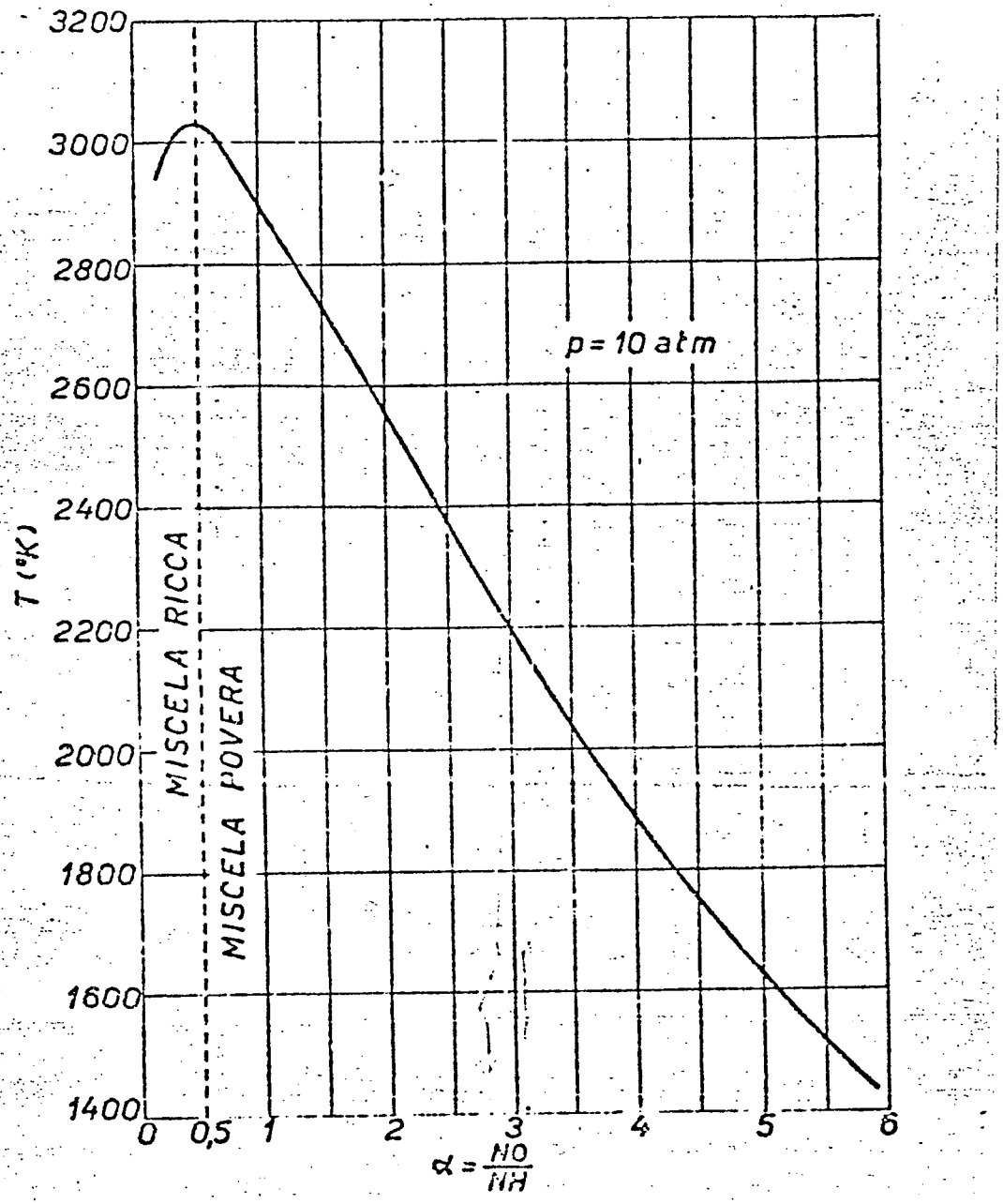


Fig. 2 - andamento della temperatura di combustione della miscela H_2-O_2

H_2O	1,999647
OH	0,000703
H_2	0,000001
H	0,000000
O_2	9,499818
O	0,000015

TAB. 1 - numero di moli dei prodotti di combustione della miscela H_2-O_2 in corrispondenza delle condizioni considerate

Fig. 2 - Development of the combustion temperature of the mixture H_2 - O_2. Table 1 - mole numbers of combustion products from the mixture H_2- O_2 in the relation to the examined conditions.

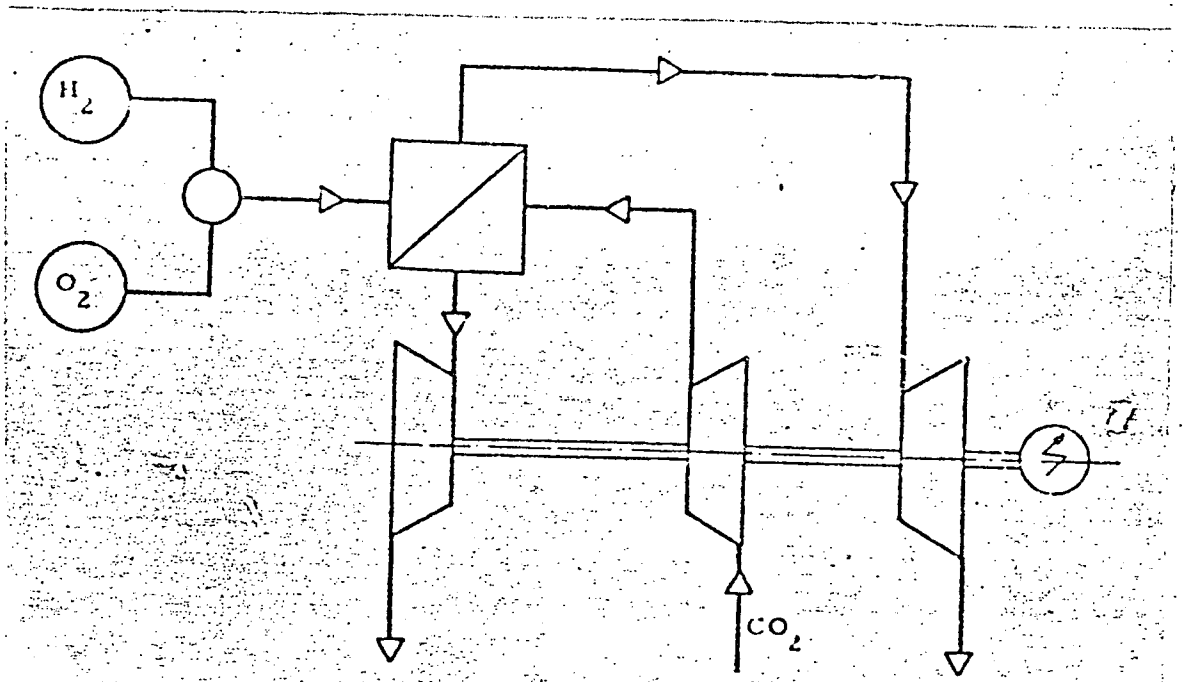


Fig. 4 - Schema di impianto relativo al caso (b)

Fig. 4 - Plant layout for case (b).

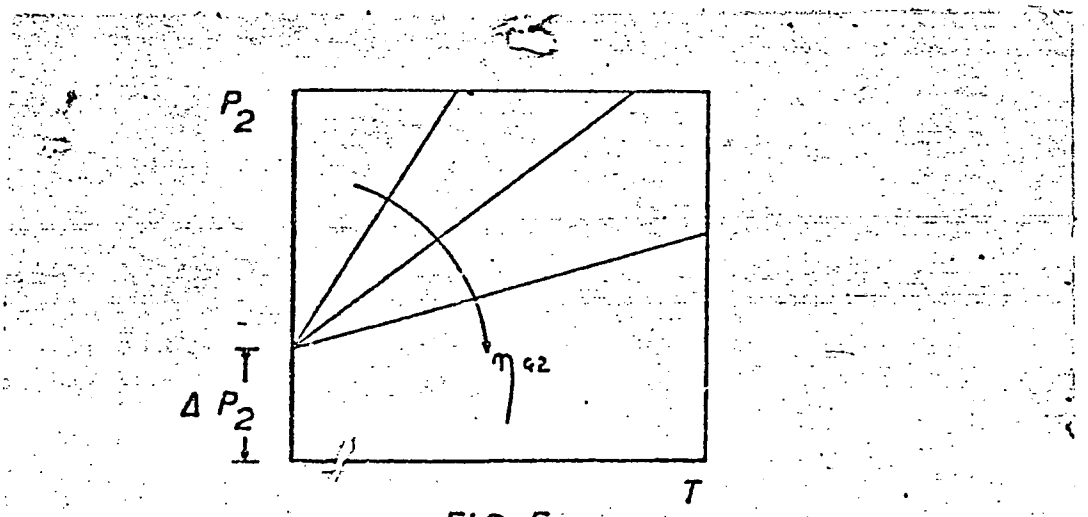


FIG. 5

Fig. 5 - Andamento del peso nel caso (b) in funzione del rendimento globale

Fig. 5 - Development of the weight in case (b) as a function of the total output.

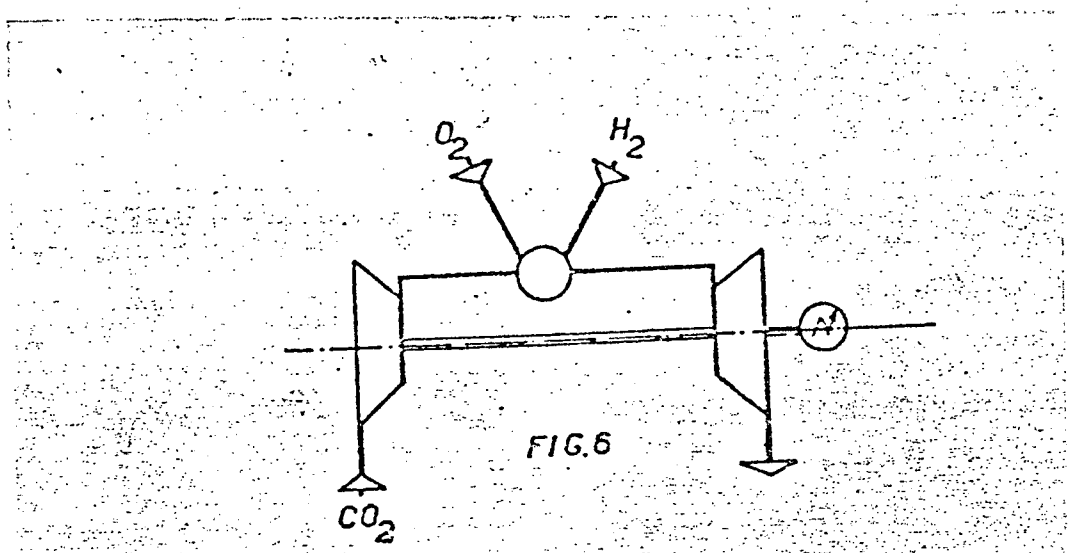


Fig. 6 - Schema di impianto relativo al caso (c)

Fig. 6 - Plant layout for case (c).

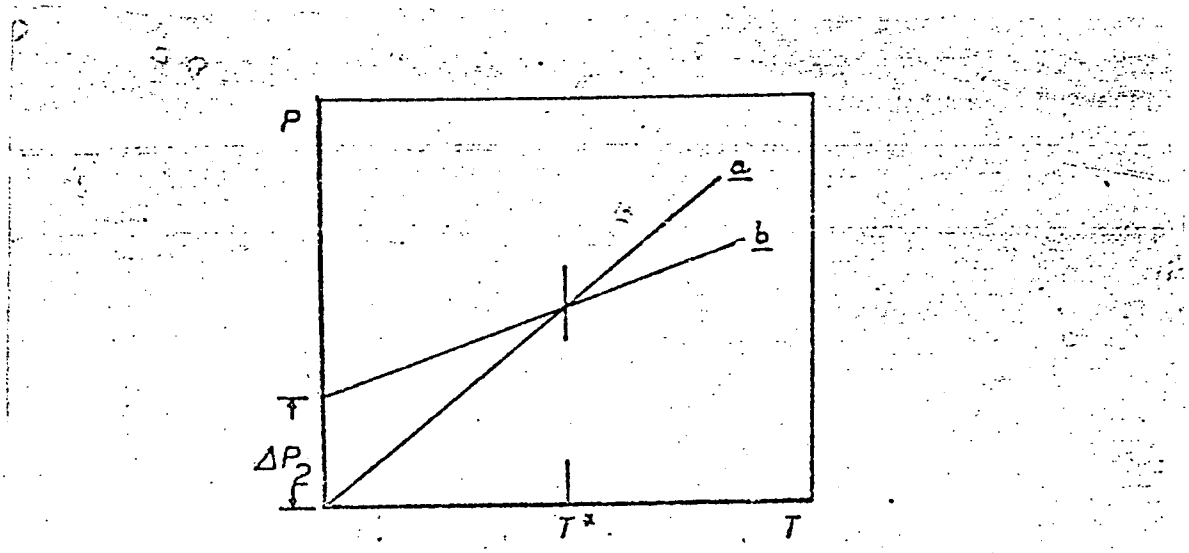


Fig. 8 - Confronto fra il primo ed il secondo caso e determinazione del tempo discriminante.

Fig. 8 - Comparison between the first and the second case and establishment of the discriminating time.

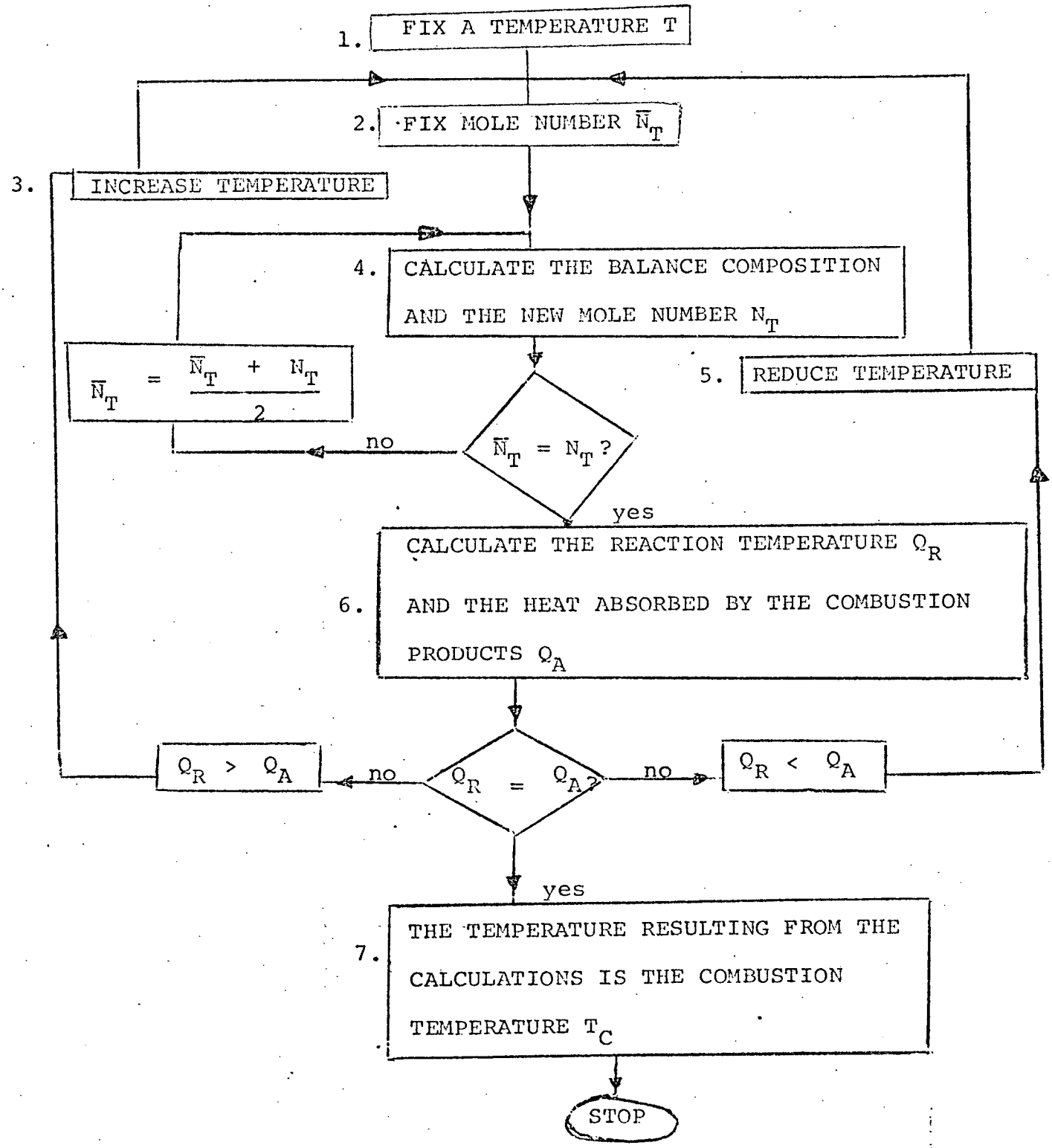

1. FIX A TEMPERATURE T
2. FIX MOLE NUMBER $\bar{N}_T$
3. INCREASE TEMPERATURE
4. CALCULATE THE BALANCE COMPOSITION AND THE NEW MOLE NUMBER N_T
$\bar{N}_T = \frac{\bar{N}_T + N_T}{2}$
$\bar{N}_T = N_T$?
no
yes
5. REDUCE TEMPERATURE
6. CALCULATE THE REACTION TEMPERATURE Q_R AND THE HEAT ABSORBED BY THE COMBUSTION PRODUCTS Q_A
$Q_R > Q_A$
$Q_R = Q_A$?
$Q_R < Q_A$
no
no
yes
7. THE TEMPERATURE RESULTING FROM THE CALCULATIONS IS THE COMBUSTION TEMPERATURE T_C
STOP

Fig. ___ - Block diagram relative to calculation of the adiabatic combustion temperature. (8.)

REFERENCES

1. Planetary atmospheres -
   Nasa SP. 7017 - 1965.
2. Handbook of physical properties of the planet Mars -
   Nasa SP. 3030 - 1967.
3. Models of Mars atmosphere -
   Nasa SP. 8010 - 1968.
4. Space power systems engineering -
   Progress in astronautics and aeronautics - Vol. 16
   Academic Press - 1966
5. Pitts, D. F. - A computer program for calculating
   model planetary atmospheres -
   Nasa T.N.D. - 4292 - Feb. 1968